NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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By E. E. Reynolds, J. W. Freeman, and A. E. White
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SUMMARY

Two turbosupercharger discs of 19-9DL alloy were included in a general investigation to determine the properties of this material in forgings of the size actually used in service. The two discs were given hot-cold-working treatments at 1300° to 1350° F. They differed only in that one was solution-treated while the other was left in the as-forged condition prior to hot-cold-working. The contour forgings were made by the Steel Improvement and Forge Company. One-half of each disc was tested by the General Electric Company. The other halves were sent to the University of Michigan for investigation for the NACA.

The small size of the discs limited the number of specimens and the extent of testing. The data obtained by the General Electric Company were therefore included in this report to give a more complete survey of the properties of the discs.

It was found that the rupture strengths at 1200° F were good. There was no appreciable difference in properties between the two forgings; the benefits of hot-cold-work on rupture strengths at 1200° F were not retained at 1350° F; rupture test ductility was very low; the discs had fair uniformity of properties; and the properties compared favorably with those of bar stock. The properties of the solution-treated disc were about average for that type of treatment. The rupture strengths of the as-forged disc at 1200° F were somewhat higher than average for 10 and 100 hours.

INTRODUCTION

Alloy 19-9DL is one of the lower-alloyed materials developed during the war for high-temperature service. The properties of this alloy in various forms have been studied extensively. This report is concerned with the properties of two approximately 12-inch-diameter turbosupercharger discs of this alloy.

The two discs differed in treatment in that one was solution-treated and the other was not. Both discs were hot-cold-worked in contour dies at 1300° to 1350° F. Both were made from the same heat used for a large gas-turbine rotor forging and bar stock concurrently investigated under NACA sponsorship. The principal object of the investigation was to determine the level of properties developed in these forgings and to show the comparison of these properties with those of the same heat of the alloy in other forms.

One-half of each of the discs was submitted for study at the University of Michigan for the NACA. The other halves were tested by the General Electric Company and their data are included in this report to give a more complete property survey. Through the courtesy of the General Electric Company Mr. W. L. Badger of their Thomson Laboratory furnished comparative rupture strengths for 15 other turbosupercharger discs. The work at the University was limited to rupture tests at 1200° and 1350° F and two creep tests at 1200° F on each disc. The investigation was conducted at the University of Michigan under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. It constitutes one phase of a research program, sponsored at the University by the NACA, on the metallurgy of heat-resisting alloys used in gas turbines for aircraft propulsion systems.

TEST MATERIAL

The available information concerning the two turbosupercharger discs, ZD1952 and ZD1957, of 19-9DL alloy is summarized as follows:

Steel producer:

The Universal-Cyclops Steel Corporation, Bridgeville, Pennsylvania

Disc manufacturer:

The Steel Improvement and Forge Company, Cleveland, Ohio

Chemical composition:

Both discs were produced from heat B10429. The chemical composition was reported to be the following percentages:

C	Mn	Si	P	S	Cr	Ni	Mo	W	Cb	Ti
0.33	1.14	0.65	0.016	0.015	19.10	9.05	1.35	1.14	0.35	0.16

Fabrication procedure:

The following information, concerned with fabrication of the two discs, was supplied by the Universal-Cyclops Steel Corporation and the General Electric Company. Both discs were fabricated the same way with the exception of the solution treatment given disc ZD1957 listed in item (3) below:

(1) Billets were obtained from a 10,000-pound arc-furnace heat

(2) Approximately 12-inch-diameter turbosupercharger discs were forged from the billets

(3) Heat treatment:
Disc ZD1952: None
Disc ZD1957: Heated at 2100° F for 1 hour and air-cooled

(4) Both discs were hot-cold-worked at 1300° to 1350° F in closed contour dies

(5) Both discs were stress-relief annealed at 1200° F for 4 hours and air-cooled

The shape of the contour forgings is shown in figures 1, 2, and 3.

EXPERIMENTAL PROCEDURE

The half sections of the two turbosupercharger discs supplied to the University of Michigan were intended to be used for rupture and creep tests at 1200° and 1350° F to time periods of 2000 hours. The following testing program was used:

(1) Rupture tests at 1200° and 1350° F

(2) Creep tests at 1200° F under stresses of 15,000 and 20,000 psi

(3) Metallographic, tensile, and hardness tests when possible to determine stability characteristics of the material

The necessary test specimens were machined from coupons cut from the forgings according to figure 1. Included in this figure is the sectioning diagram for the halves of the discs tested by the General Electric Company. Locations of the General Electric Company tensile specimens are shown in figures 2 and 3. Creep tests were conducted on 0.400-inch-diameter specimens with a 2-inch gage length. The specimens for rupture tests were 0.160-inch diameter with a 1-inch gage length.

RESULTS

The small size of the discs limited the number of specimens and the extent of testing. For this reason General Electric Company tensile, hardness, and rupture data for the two discs have been included in this report to supplement the rupture and creep data obtained at the University. The data are presented as a series of tables and figures which show the rupture, time-deformation, creep, stability, hardness, and tensile characteristics.

Rupture Test Characteristics

The rupture test data at 1200° and 1350° F are given in table I. The usual double-logarithmic curves of stress against rupture time are shown in figure 4. Rupture strengths and estimated ductilities to fracture are included in table I.

There was no appreciable difference in rupture strength between the two forgings at either temperature. At 1200° F strengths for rupture in 100 and 1000 hours were 52,000 and 37,000 psi, respectively. Corresponding strengths at 1350° F were 24,000 and 13,000 psi. The ductility to fracture was very low for both discs, ranging from 1 to 3 percent elongation at both 1200° and 1350° F.

Time-Deformation Characteristics

This type of information is limited to results from two creep tests and several low-deformation rupture tests at 1200° F. The available time-deformation data are given in table II and plotted to coordinates of stress against the logarithm of time in figure 5. These data were obtained from the curves of time against elongation from the creep tests and rupture tests. From the limited data it was estimated that the two discs had the same time-deformation strengths. These are given in table III. Figure 5 and table III include comparative data for the large forged gas-turbine disc made from the same heat, B10429. (See reference 1.) The hot-cold-worked turbosupercharger discs had substantially higher deformation resistance at total deformations above 0.1 percent than the large forged disc.

Creep Strengths

Creep rates for the creep and rupture tests at 1200° F are given in table II. The creep rates from the creep tests are those at 1000 hours. It appeared from the creep test of 2000-hour duration at 20,000 psi on disc ZD1952 that the 1000-hour creep rates were probably higher than the minimum rates which would have been obtained if the tests had been continued for longer time periods.

Creep rates are plotted against stress on double-logarithmic coordinates in figure 6. Because of the very limited amount of creep test data obtained for the turbosupercharger discs, the curve of stress against creep rate for the large forged turbine disc of 19-9DL is drawn on this figure and the points for the turbosupercharger discs compared with this curve. The creep strengths of the turbosupercharger discs were estimated to be approximately equal and were the same as those for the large disc. These strengths were 25,000 psi to produce a creep rate of 0.0001 percent per hour and 11,000 psi for a rate of 0.00001 percent per hour.

Stability Characteristics

After creep testing at 1200° F, the room-temperature tensile properties of a specimen from disc ZD1952 were substantially the same as those of the original material. (See table IV.) There was a decrease in hardness during rupture testing of both discs, this decrease being quite appreciable at 1350° F.

The microstructures of the original material and of specimens after completion of rupture tests are shown in figures 7, 8, and 9. The original microstructure indicated that there was more fine precipitated phase present in disc ZD1957, which was solution-treated prior to hot-cold-work, than in disc ZD1952. A considerable variation in grain size within each disc is indicated by the difference in grain sizes of the 1200° F rupture specimens and the samples used for the original structures.

Rupture testing at 1200° F did not change the structure noticeably. There was considerable precipitation and agglomeration of excess constituents during testing at 1350° F which, with the accompanying hardness decrease, indicate structural instability in the material.

Data from the General Electric Company Laboratory

Half sections of each of the two turbosupercharger discs were examined by the General Electric Company for tensile properties at room temperature, 1200°, and 1500° F, hardness at room temperature, and rupture characteristics at 1200° F. Tensile and hardness data are given in figures 2 and 3. The rupture test data are plotted in figure 4 with the University of Michigan results. (See reference 2.)

The Brinell hardness tended to be higher near the rim than near the center of each disc. No apparent difference in hardness existed between the discs. The discs had similar tensile properties. There was a slight tendency for the material from near the center to be weaker than material from near the rim. The ductility tended to be less at 1200° F than at room temperature or at 1500° F.

DISCUSSION OF RESULTS

There were no appreciable differences observed in any of the properties of the two turbosupercharger discs of 19-9DL alloy. The solution treatment prior to hot-cold-work on the one disc is therefore considered to have had no appreciable effect on the properties studied. It should be recognized, however, that the forging conditions could have been equivalent to an effective solution treatment if the finishing temperature had been high. The solution treatment on disc ZD1957 would have had little effect under this condition and would not have appreciably changed its structure from that of disc ZD1952 which probably was effectively solution-treated during forging.

An unusual opportunity to determine how well the two discs covered by this investigation represent the properties of average production of such discs is provided by the data in table V. The General Electric Company furnished the rupture strengths at 1200° F used in this table for 15 other discs. The solution-treated and hot-cold-worked disc ZD1957 had properties quite close to the average for discs treated in that manner. Somewhat higher properties than average were exhibited by the forged and hot-cold-worked disc ZD1952.

The data in table V indicate that solution-treating prior to hot-cold-work does have the advantage of improving rupture strength at 10 and 100 hours at 1200° F. The forged and aged discs were somewhat stronger at 1000 hours. Both types of treatment, however, result in a spread in properties between different discs. The data for disc ZD2273 also illustrate the possibility of an occasional disc of very low strength when a solution treatment is omitted.

Heat B10429 of 19-9DL has been tested also as a large forged gas-turbine disc and as bar stock. A comparison of tensile and rupture properties for these forms is given in table VI. Included in this table are data for two 20-inch-diameter contour-forged discs of 19-9DL alloy made from another heat.

The two turbosupercharger discs had rupture strength and ductility at 1200° F similar to those of bar stock R19-9DL, which had been hot-cold-worked 20 percent at 1200° F. However, tensile test strength properties were lower than those of hot-cold-worked bar stock. The turbosupercharger discs were superior in tensile and 1200° F rupture strength to the large as-forged turbine disc of the same heat. However, they had much lower rupture test ductility than the large disc.

The turbosupercharger discs had properties quite similar to the large contour disc hot-cold-worked at 1250° F. The contour disc hot-cold-worked at 1650° F had lower strength and higher ductility.

The superiority of hot-cold-worked over as-forged 19-9DL discs in rupture strength at 1200° F diminished with time. The hot-cold-worked material did not exhibit any improvement in ductility with time and in this respect was still quite inferior to the forged or solution-treated material at long time periods. Rupture tests at 1350° F indicated that the improvement in strength properties at 1200° F due to hot-cold-work was not retained at higher temperatures and that the low rupture ductility was still present. The 100- and 1000-hour rupture strengths at 1350° F for the large as-forged disc were 23,000 and 13,500 psi, which were similar to the strengths for the smaller hot-cold-worked turbosupercharger discs. Corresponding rupture ductilities were 35 and 23 percent as compared with approximately 2 percent for the smaller discs. The structural instability of the small discs at 1350° F, which was similar to that of the larger gas-turbine disc, probably accounts for this equalization of strengths at 1350° F.

The erratic results in the rupture tests at 1200° F shown by both the Michigan and General Electric data (see fig. 4) are probably partially due to variation in sample location and partially to an inherent erratic characteristic associated with the low deformations in the materials. The location of the samples cut from such discs does have considerable influence on the resulting rupture strength. Likewise the erratic test data from specimens from discs may provide somewhat misleading results if sufficient tests are not run to obtain a good average curve of stress against rupture time. The difference in reported rupture strengths for discs ZD1952 and ZD1957 between that indicated by the combined data from two laboratories in figure 4 and the values based on a limited number of tests from one laboratory in table V illustrates the need for complete test data. Both factors may have contributed to the wide spread in rupture strengths indicated by table V as well as actual strength differences between discs.

From the results for these two turbosupercharger discs, it is believed that hot-cold-working such discs develops rupture and time-deformation strengths at 1200° F near the top limit of the range in these properties obtained for 19-9DL alloy as bar stock.

CONCLUSIONS

From a study of the properties at room temperature, 1200°, and 1350° F of two turbosupercharger discs of 19-9DL alloy the following conclusions were made:

1. No particular improvement in properties over an as-forged disc was obtained from a solution treatment when subsequent hot-cold-work was used.

2. The rupture properties at 1200° F of the disc solution treated before hot-cold-working were probably quite typical of the treatment. The disc hot-cold-worked in the as-forged condition had somewhat higher rupture strength at 10 and 100 hours than the average for that type of treatment.

3. The lack of improvement in properties from a solution treatment was probably related to the forging conditions. It suggests that the finishing conditions during forging were such as to solution-treat effectively both discs and the subsequent solution treatment of one of the

discs did not have an appreciable added effect. Other forging conditions could result in quite different comparative results.

4. Hot-cold-working the turbosupercharger discs developed strength properties at 1200° F at the high end of the range of properties possible for this alloy. At 1350° F no beneficial effect was obtained from hot-cold-work. Rupture test ductility of the hot-cold-worked material was very low at both 1200° and 1350° F.

5. The two discs showed fair uniformity of properties. Erratic rupture test times at 1200° F were probably due in part to sample location and in part to an inherent erratic characteristic of hot-cold-worked material with low rupture deformation.

6. The properties of bar stock of 19-9DL were reproduced quite well in the turbosupercharger discs.

University of Michigan
Ann Arbor, Mich., May 26, 1947

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3. Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of Two Contour-Forged Gas-Turbine Discs of 19-9DL Alloy. NACA TN No. 1532, 1948.

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TABLE I

RUPTURE TEST CHARACTERISTICS AT 1200° AND 1350° F

OF TURBOSUPERCHARGER DISCS OF 19-9DL ALLOY

[All specimens were radial near the rim]

Disc	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
ZD1952 (Forged; hot-cold-worked)	1200	60,000 50,000 45,000 40,000 37,500	26 141 289 282 957	5 1.5 1 1 2	3.7 3.7 1.2 1.2 3.2
ZD1957 (Forged; solution-treated; hot-cold-worked)	1200	55,000 50,000 40,000 35,000	34 212 504 1475	1.5 3.5 1 2	3.1 5.1 2.3 2.4
ZD1952	1350	30,000 22,500 20,000 15,000	38 152 235 601	2.5 2 3 0	2.5 3.7 4.0 0
ZD1957	1350	30,000 25,000 20,000 17,000	40.5 62 172 348	3 2 4 2	1.2 3.7 3.1 2.3

Rupture strength

Disc	Test temperature (°F)	Stress (psi) for rupture in –		
		10 hr	100 hr	1000 hr
ZD1952	1200	[a]58,000	52,000	37,000
ZD1957	1200	[a]58,000	52,000	37,000
ZD1952	1350	------	24,000	13,000
ZD1957	1350	------	24,000	13,000

Rupture ductility

Disc	Test temperature (°F)	Estimated elongation (percent) to rupture in –		
		10 hr	100 hr	1000 hr
ZD1952	1200	5	2	2
ZD1957	1200	3	3	2
ZD1952	1350	-	2	1
ZD1957	1350	-	3	1

[a]Estimated.

TABLE II

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F

FOR TURBOSUPERCHARGER DISCS OF 19-9DL ALLOY

Disc	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –				Transition to third-stage creep (a)		Creep rate (percent/hr)
			0.1 percent	0.2 percent	0.5 percent	1 percent	Time (hr)	Deformation (percent)	
ZD1952	15,000	0.0725	38	----	---	---	----	---	[b]0.000029
	20,000	.1005	---	1170	---	---	----	---	[b].000053
	37,500	[c].19	---	----	75	580	760	1.1	[d].0003
	40,000	[c].20	---	----	8	40	----	---	[d].0010
	45,000	[c].23	---	----	---	1	----	---	[d].0027
	50,000	------	---	----	---	---	----	---	--------
	60,000	------	---	----	---	---	----	---	--------
ZD1957	15,000	.0728	325	----	---	---	----	---	--------
	20,000	.1090	---	1060	---	---	----	---	[b].000047
	35,000	[c].17	---	----	190	810	1400	1.5	[d].0005
	40,000	[c].20	---	----	20	430	----	---	[d].0006
	50,000	[c].27	---	----	---	35	100	1.3	[d].0022
	55,000	-------	---	----	---	---	----	---	--------

[a]Most of the rupture tests showed no apparent evidence of third-stage creep prior to fracture.
[b]Creep rate at 1000 hr for creep tests.
[c]Initial deformations for rupture tests estimated from stress-strain curves from tensile tests at 1200° F.
[d]Minimum creep rate for rupture tests.

TABLE III

TIME-DEFORMATION STRENGTHS AT 1200° F OF TWO TURBOSUPERCHARGER

DISCS AND A GAS-TURBINE DISC OF 19-9DL ALLOY

Type forging	Total deformation (percent)	Stress (psi) to cause total deformation in –		
		10 hr	100 hr	1000 hr
Turbosupercharger discs ZD1952 and ZD1957 (Approximately 12 in. in diameter.)	0.1	17,000	15,000	13,000
	.2	27,000	23,500	20,000
	.5	41,000	36,500	32,000
	1.0	48,000	41,000	35,000
	Transition	------	50,500	36,500
Turbine disc[1] (cheese forging) (Approximately 20 in. in diameter.)	.1	16,000	14,000	12,000
	.2	24,000	21,000	17,000
	.5	29,000	26,000	23,500
	1.0	32,500	29,000	26,000
	Transition	------	39,000	33,000

[1]See reference 1.

TABLE IV

EFFECT OF CREEP AND RUPTURE TESTING ON THE PHYSICAL PROPERTIES OF TURBOSUPERCHARGER DISCS OF 19-9DL ALLOY

Disc	Prior testing conditions				Residual room-temperature properties				
	Type test	Temperature (°F)	Stress (psi)	Time (hr)	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation (percent)	Reduction of area (percent)	Vickers hardness
ZD1952	(a)	(a)	(a)	(a)	[b]133,600	[b]84,900	[b]25	[b]33	340
	Creep	1200	20,000	2600	135,000	71,500	16	33	---
	Rupture	1200	37,500	957	-------	------	--	--	320
	Rupture	1350	15,000	601	-------	------	--	--	288
ZD1957	(a)	(a)	(a)	(a)	[b]132,100	[b]83,200	[b]21	[b]33	323
	Rupture	1200	35,000	1475	-------	------	--	--	306
	Rupture	1350	17,000	348	-------	------	--	--	288

[a]Original condition.

[b]General Electric Company data. Average for radial specimens.

TABLE V

RUPTURE STRENGTHS OF 17 TURBOSUPERCHARGER DISCS AT 1200° F

Forged; solution-treated; hot-cold-worked				Forged; hot-cold-worked			
Disc	Rupture strengths (psi)			Disc	Rupture strengths (psi)		
	10 hr	100 hr	1000 hr		10 hr	100 hr	1000 hr
General Electric Company data							
ZD1957	50,000	47,000	31,000	ZD1952	54,100	44,200	------
A-576	------	52,500	39,000	RC82	58,500	48,000	39,000
A-631	------	51,000	------	ZC10014	------	48,000	------
A-711	61,500	55,000	36,000	ZD2273	------	44,800	25,600
A-638	65,500	47,500	34,400	ZD1994	53,000	44,000	36,300
A-760	------	53,000	37,000	ZD2015	51,800	47,000	43,000
A-761	------	56,000	------	ZD1945	47,000	42,000	40,500
ZD2265	60,000	45,000	33,800	ZD1978	56,500	50,000	43,000
				ZD1967	60,300	50,800	43,000
Average	59,300	50,900	35,200	Average	54,500	46,500	38,600
University of Michigan results							
[a]ZD1957	58,000	52,000	37,000	[a]ZD1952	58,000	52,000	37,000

[a]Rupture strengths, for the two discs covered by this report, based on the combined test data from the University of Michigan and the General Electric Company. (See fig. 4.)

TABLE VI

COMPARATIVE PROPERTIES OF TURBOSUPERCHARGER DISCS, GAS-TURBINE DISCS, AND BAR STOCK OF 19-9DL ALLOY

Type forging	Heat number	Processing (1)				Room-temperature physical properties (average for radial specimens on discs)					Rupture properties at 1200° F			
		Heat treatment			Hot-cold-work temperature (°F)	Tensile strength (psi)	Yield strength (psi)		Elongation (percent)	Brinell hardness	100 hr		1000 hr	
		Temperature (°F)	Time (hr)	Cooling			0.02 percent	0.2 percent			Strength (psi)	Elongation (percent) (2)	Strength (psi)	Elongation (percent) (2)
Disc ZD1952	H10429	----	---	----	1300 to 1350	133,600	84,900	------	25	250-300	52,000	2	37,000	2
Disc ZD1957	H10429	2100	1	A.C.[3]	1300 to 1350	132,100	83,200	------	21	260-300	52,000	3	37,000	2
Disc[4] (cheese forging)	H10429	(5)	(5)	(5)	------------	104,700	39,875	54,700	30	185-220	40,000	27	34,000	16
Contour disc[6] (EXC44)	H11728	2150	2	W.Q.[7]	1250	119,600	70,500	90,500	26	246-253	47,000	3	38,500	1
Contour disc[6] (EXC46)	H11728	2150	2	W.Q.	1650	102,500	39,000	58,000	34	200-223	36,500	20	32,000	14
19-9DL bar stock[8]	H10429	(9)	(9)	(9)	------------	131,000	70,500	90,000	32	242-252	------	--	------	--
S19-9DL bar stock[8]	H10429	2100	1	W.Q.	------------	102,350	26,500	42,250	53	186-189	43,000	20	34,500	20
R19-9DL bar stock[8]	H10429	(9)	(9)	(9)	1200 (20 percent)	154,200	100,250	125,000	24	321-335	53,000	2	38,000	3

[1]All forgings were given a final stress-relief treatment at 1200° F.
[2]Estimated.
[3]A.C., air-cooled.
[4]See reference 1.
[5]Hot-forged to 1640° F.
[6]See reference 3.
[7]W.Q., water-quenched.
[8]See reference 4.
[9]Hot-rolled to 1640° F.

NACA

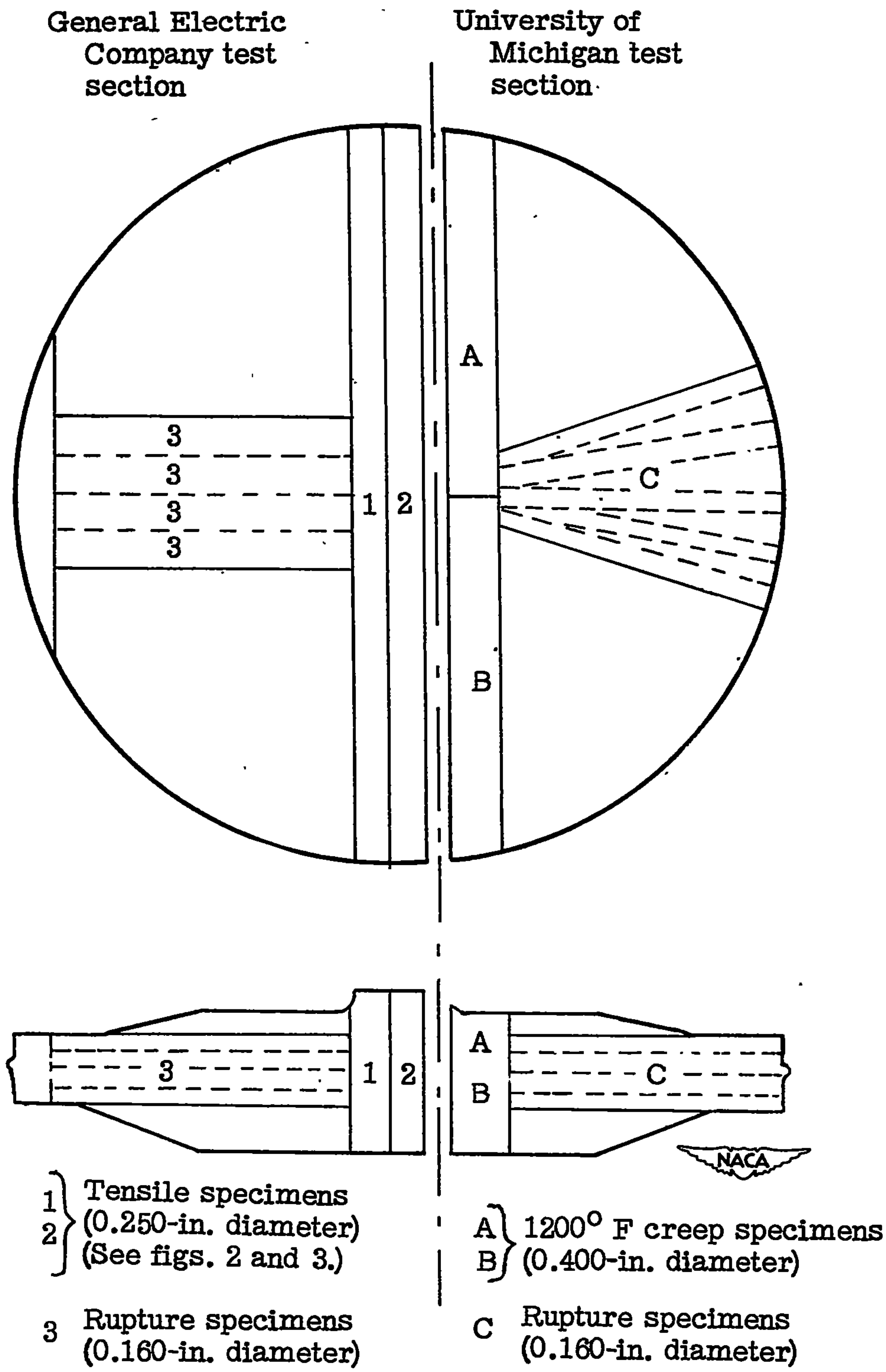


Figure 1.- Location of test coupons in two turbosupercharger discs (ZD1952 and ZD1957) of 19-9DL alloy.

Universal-Cyclops certified chemical analysis										
C	Mn	P	S	Si	Cr	Ni	Mo	W	Ti	Cb
0.33	1.14	0.016	0.015	0.65	19.10	9.05	1.35	1.14	0.16	0.35

Test tempera-ture (°F)	0.250-in. specimens pulled at test temperatures				
	Speci-men	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elonga-tion in 1 in. (percent)	Reduction of area (percent)
Room	1	132,600	90,000	32	40
Room	2	131,600	86,700	28	37
1200	3	84,700		19	40
1200	4	82,000		17	37
1500	5	52,650		21	43
1500	6	53,600		32	45

Test tempera-ture (°F)	Slice 1 0.250-in. specimens pulled at test temperatures				
	Speci-men	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elonga-tion in 1 in. (percent)	Reduction of area (percent)
Room	1	133,600	82,050	27	38
Room	2	132,600	84,500	26	27
Room	6	145,000	92,850	22	22
Room	7	106,100	62,050	11	18
1200	3	86,400		10	31
1200	4	87,200		16	25
1200	5	83,450		12	20
1200	8	82,050		12	19

Test tempera-ture (°F)	Slice 2 0.250-in. specimens pulled at test temperatures				
	Speci-men	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elonga-tion in 1 in. (percent)	Reduction of area (percent)
Room	1	134,650	88,200	23	33
Room	5	136,700	89,400	19	14
1200	2	84,400		15	25
1200	8	73,200		7	10
1500	6	56,050		11	20
1500	7	50,300		22	47

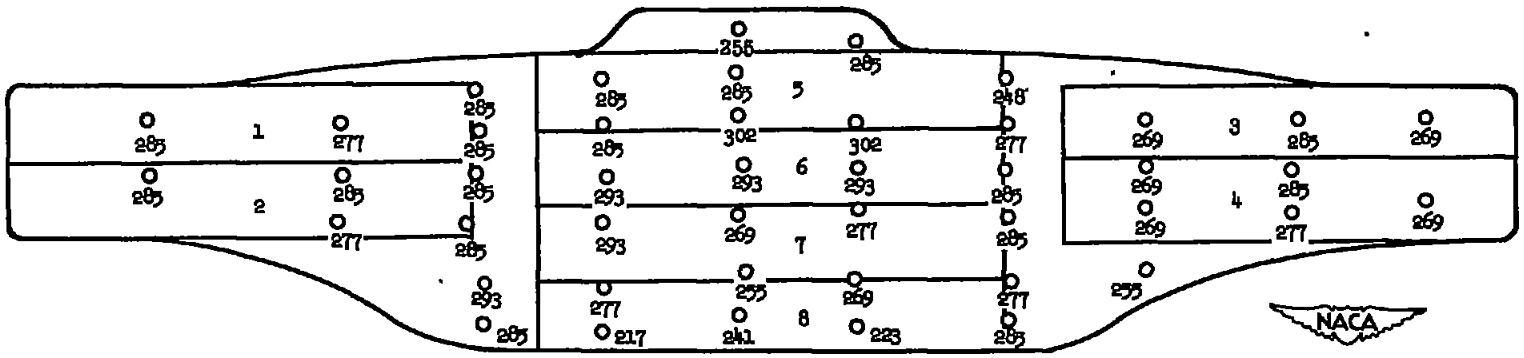


Figure 2.- General Electric Company data on disc ZD1952 of 19-9DL alloy. (Data from reference 2.) Drawing represents two slices from the center section of the disc, giving 16 short-time test specimens.

Universal-Cyclops certified chemical analysis										
C	Mn	P	S	Si	Cr	Ni	Mo	W	Ti	Cb
0.33	1.14	0.016	0.015	0.65	19.10	9.05	1.35	1.14	0.16	0.35

Physical treatment by steel improvement
Solution-treated 2100° F for 1 hr, air-cooled

Test temperature (°F)	0.250-in. specimens pulled at test temperatures				
	Specimen	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation in 1 in. (percent)	Reduction of area (percent)
Room	1	136,650	85,250	28	31
Room	2	137,750	85,100	29	34
Room	3	133,700	87,550	24	23
1200	4	87,150		17	37
1200	5	86,800		14	33
1200	6	89,300		15	32
1500	7	48,200		32	53
1500	8	54,600		21	37
1500	9	54,100		20	42

Test temperature (°F)	Slice 1				
	0.250-in. specimens pulled at test temperatures				
	Specimen	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation in 1 in. (percent)	Reduction of area (percent)
Room	1	133,650	81,850	23	35
Room	2	130,550	84,500	19	35
Room	6	136,750	84,500	18	28
Room	8	115,300	71,200	17	33
1200	3	109,750		15	31
1200	4	88,200		12	33
1200	5	83,400		15	29
1200	7	83,500		11	16

Test temperature (°F)	Slice 2				
	0.250-in. specimens pulled at test temperatures				
	Specimen	Tensile strength (psi)	0.02-percent-offset yield strength (psi)	Elongation in 1 in. (percent)	Reduction of area (percent)
Room	6	134,650	82,000	22	25
1200	3	86,150		14	35
1200	8	83,700		5	9
1500	1	50,600		31	64
1500	2	52,450		15	29
Room	4	130,600	84,100	20	29
1500	5	48,475		26	54
1500	7	50,700		24	35

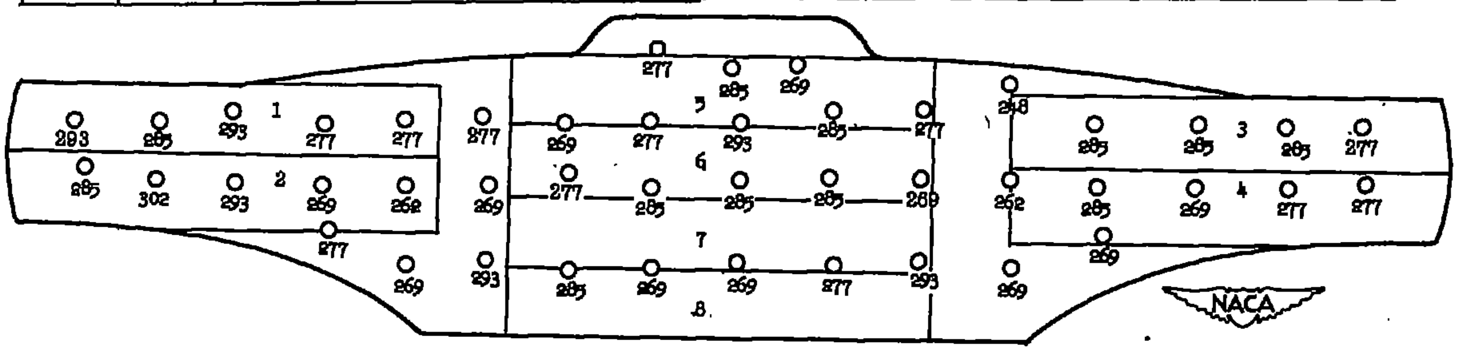
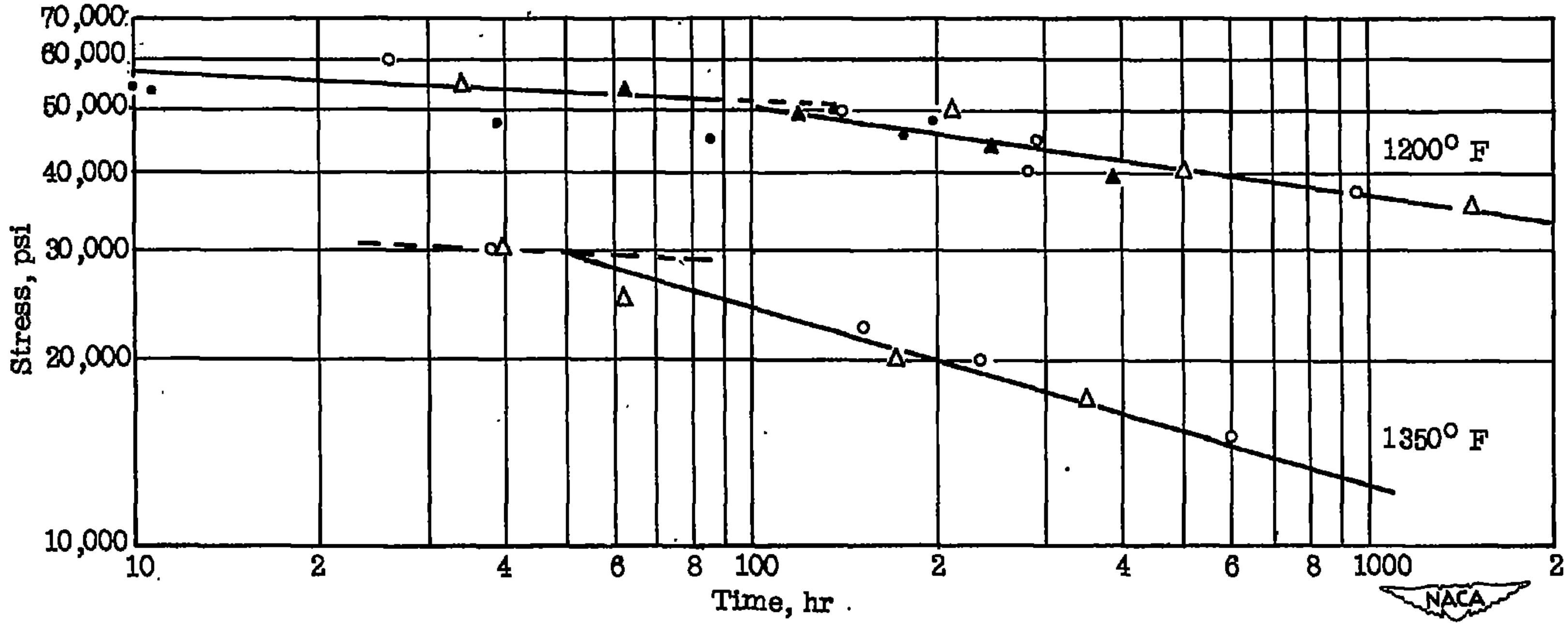


Figure 3.- General Electric Company data on disc ZD1957 of 19-9DL alloy. (Data from reference 2.) Drawing represents two slices from the center section of the disc, giving 16 short-time test specimens.



Disc	Source of Data	Treatment
○ ZD1952	University of Michigan	Forged; hot-cold-worked
● ZD1952	General Electric Company	
△ ZD1957	University of Michigan	Forged; solution-treated; hot-cold-worked
▲ ZD1957	General Electric Company	

Figure 4.- Curves of stress against rupture time at 1200° and 1350° F for turbosupercharger discs of 19-9DL alloy.

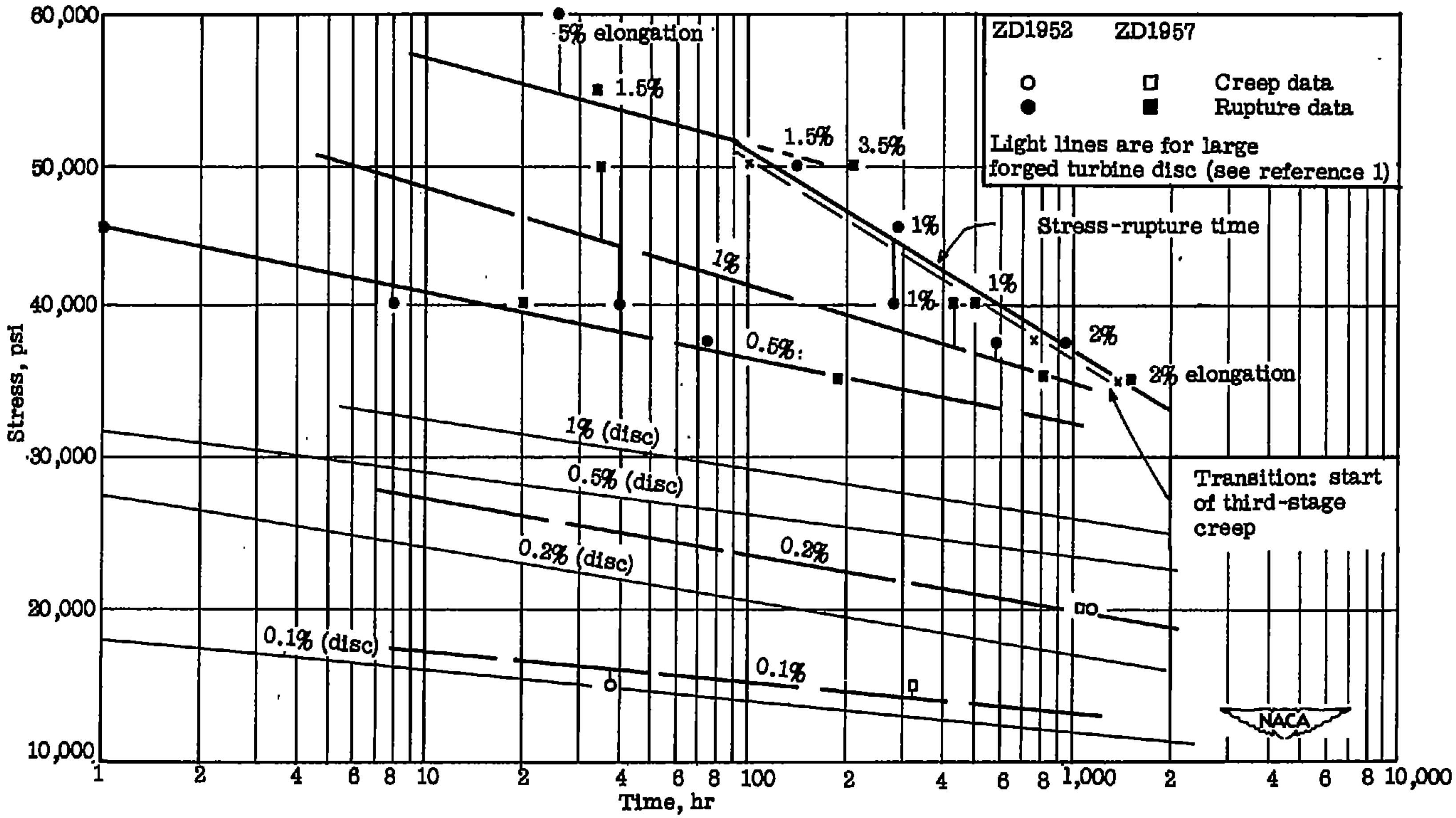
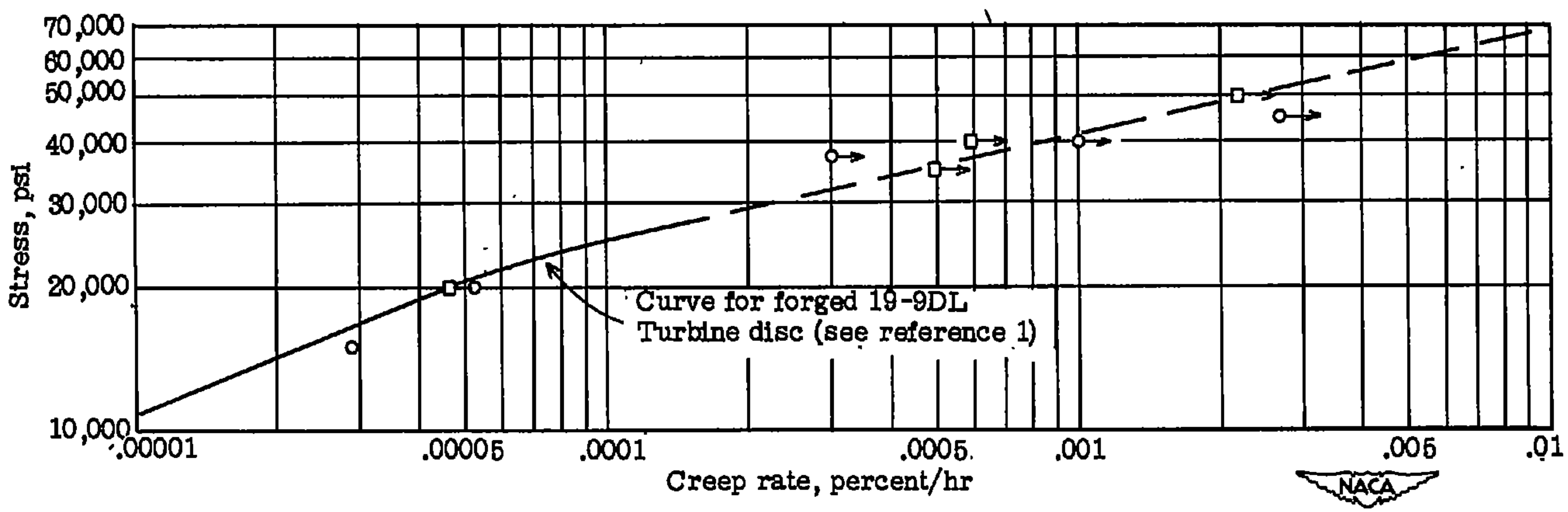


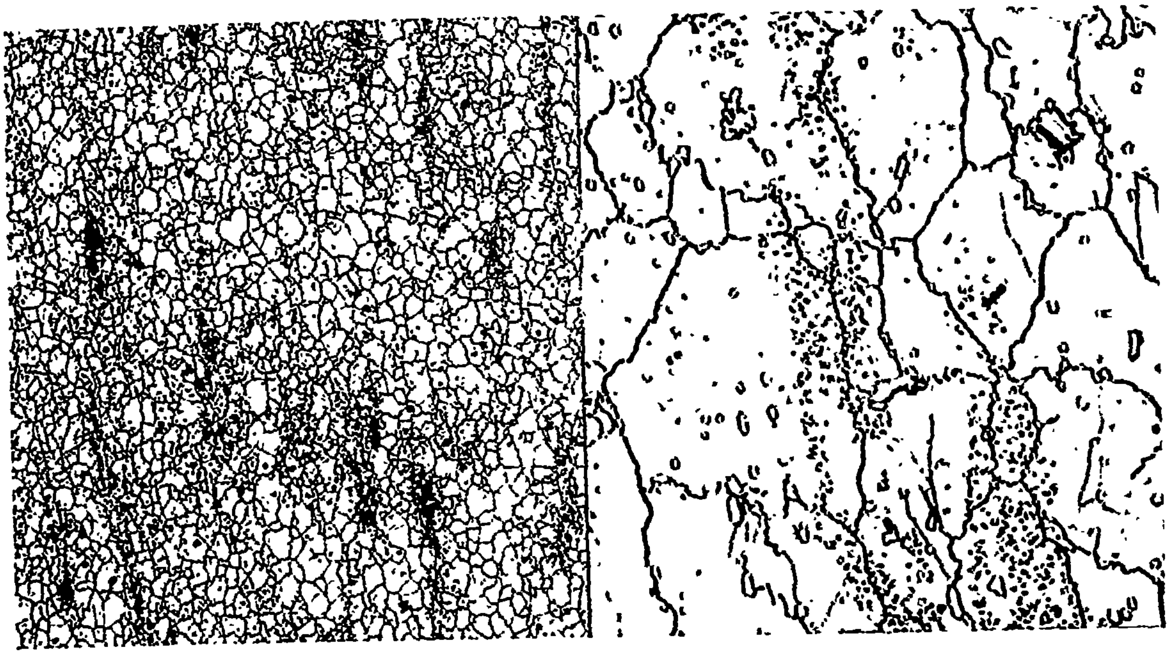
Figure 5.- Curves of stress against time for total deformation at 1200° F for two turbosupercharger discs and a turbine disc of 19-9DL alloy.



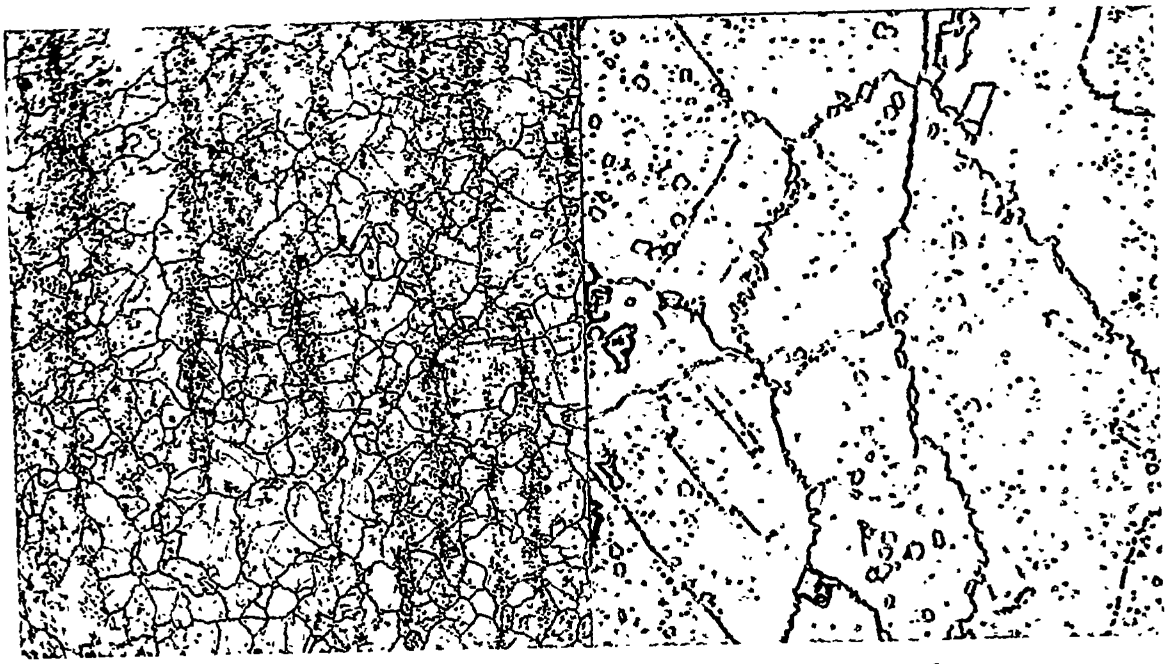
Disc	Treatment
o ZD1952	Forged; hot-cold-worked
□ ZD1957	Forged; solution-treated; hot-cold-worked

→ Test entered third-stage creep

Figure 6.- Curve of stress against creep rate at 1200° F for two turbosupercharger discs and a turbine disc of 19-9DL alloy. All data above 25,000 psi from rupture tests.



(a) Disc ZD1952; radial section near rim of disc.

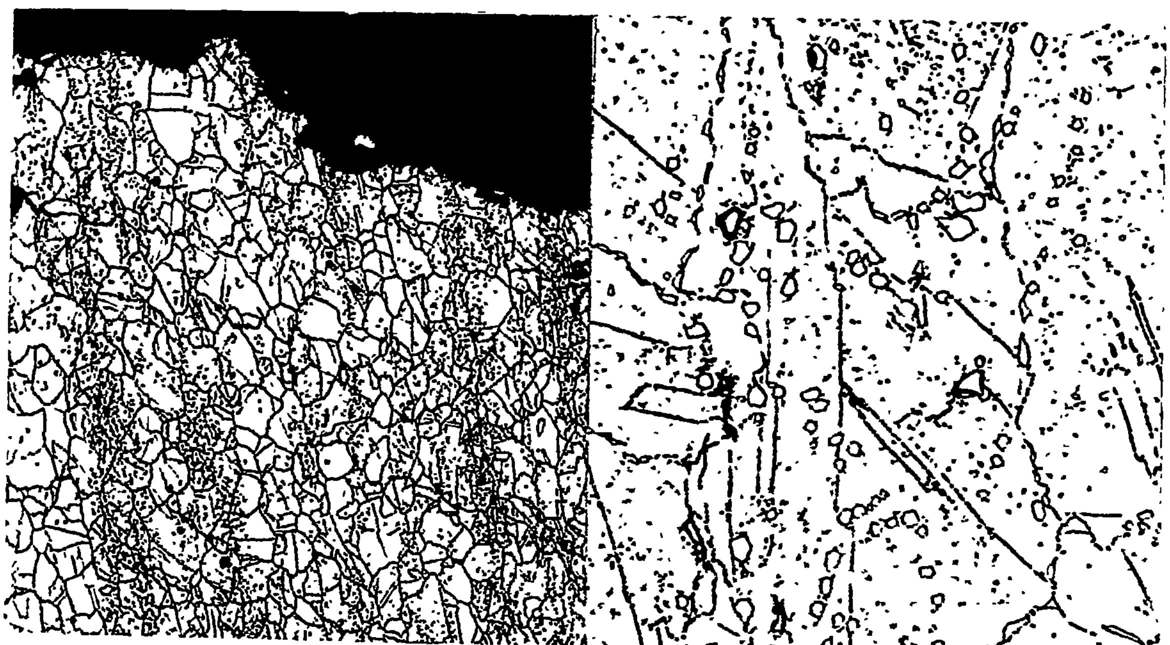


(b) Disc ZD1957; radial section near rim of disc.

Figure 7.- Original microstructures of turbosupercharger discs of 19-9DL alloy. Electrolytic chromic acid etch.

Fracture - 100X　　　　　　　　Interior - 1000X

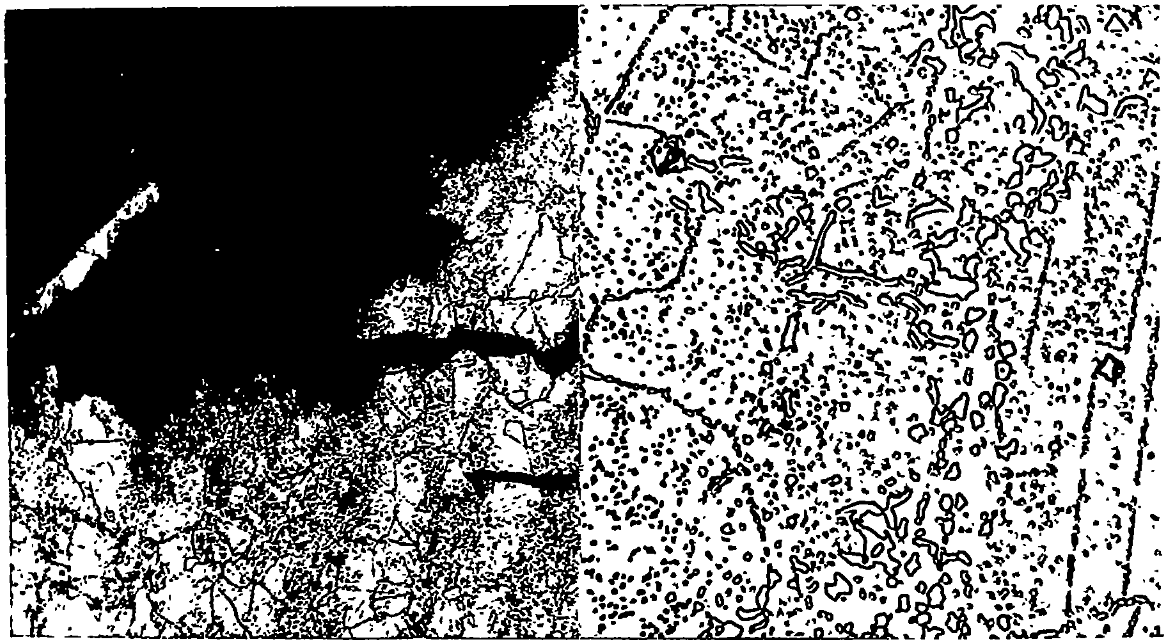
(a) Disc ZD1952; 957 hours for rupture under 37,500 psi.



Fracture - 100X　　　　　　　　Interior - 1000X

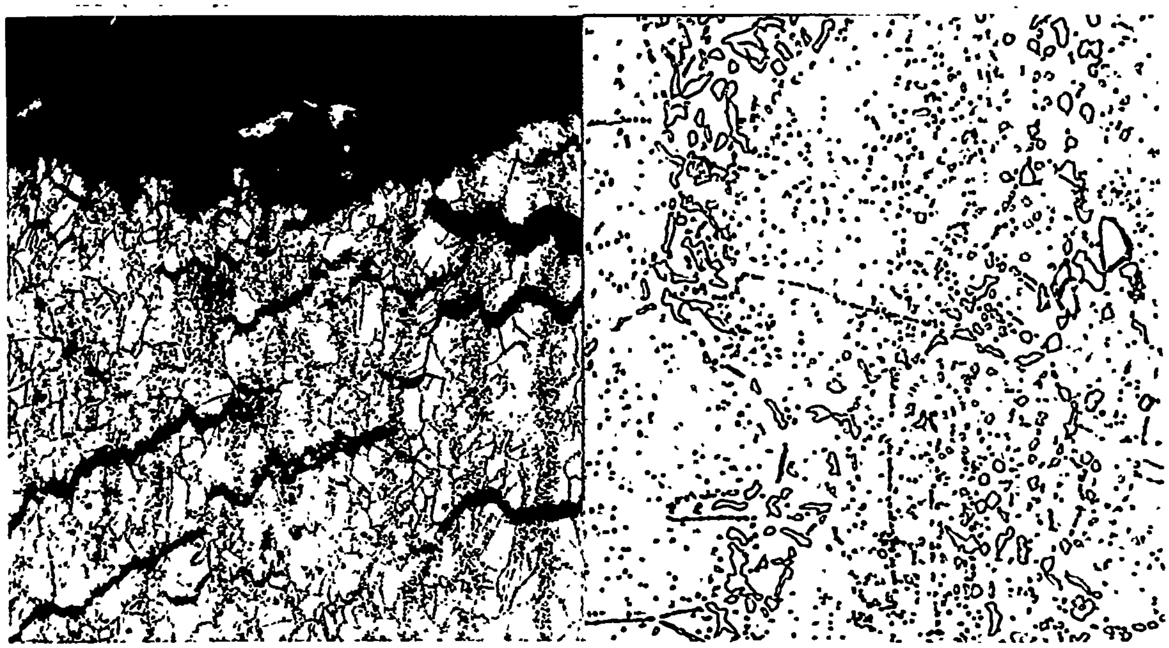
(b) Disc ZD1957; 1457 hours for rupture under 35,000 psi.

Figure 8.- Microstructures of 1200° F rupture specimens of turbosupercharger discs of 19-9DL alloy. Electrolytic chromic acid etch.



Fracture - 100X Interior - 1000X

(a) Disc ZD1952; 601 hours for rupture under 15,000 psi.



Fracture - 100X Interior - 1000X

(b) Disc ZD1957; 348 hours for rupture under 17,000 psi.

Figure 9.- Microstructures of 1350° F rupture specimens of turbosupercharger discs of 19-9DL alloy. Electrolytic chromic acid etch.